

TPF Coronagraph Science

Wesley A. Traub
Harvard-Smithsonian Center for Astrophysics

2nd TPF-Darwin Conference, San Diego

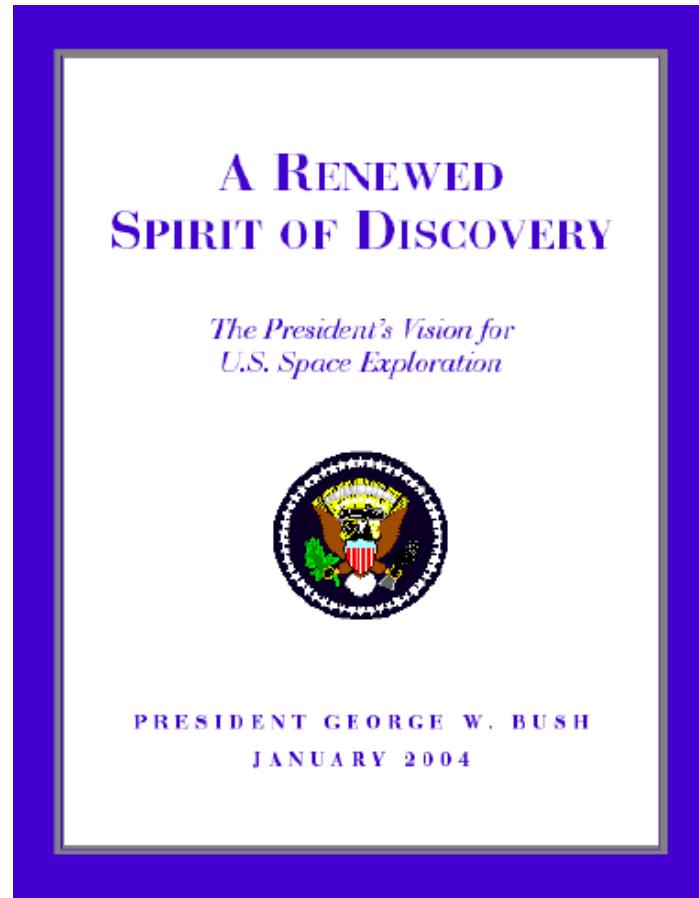
29 July 2004

Outline

- TPF today
- Planet colors and spectra; zodi
- Coronagraphs

New NASA Direction

January 2004



The President set 20 specific goals for NASA, including
**“Conduct advanced telescope searches for Earth-like planets
and habitable environments around other stars”**

Two TPF missions planned

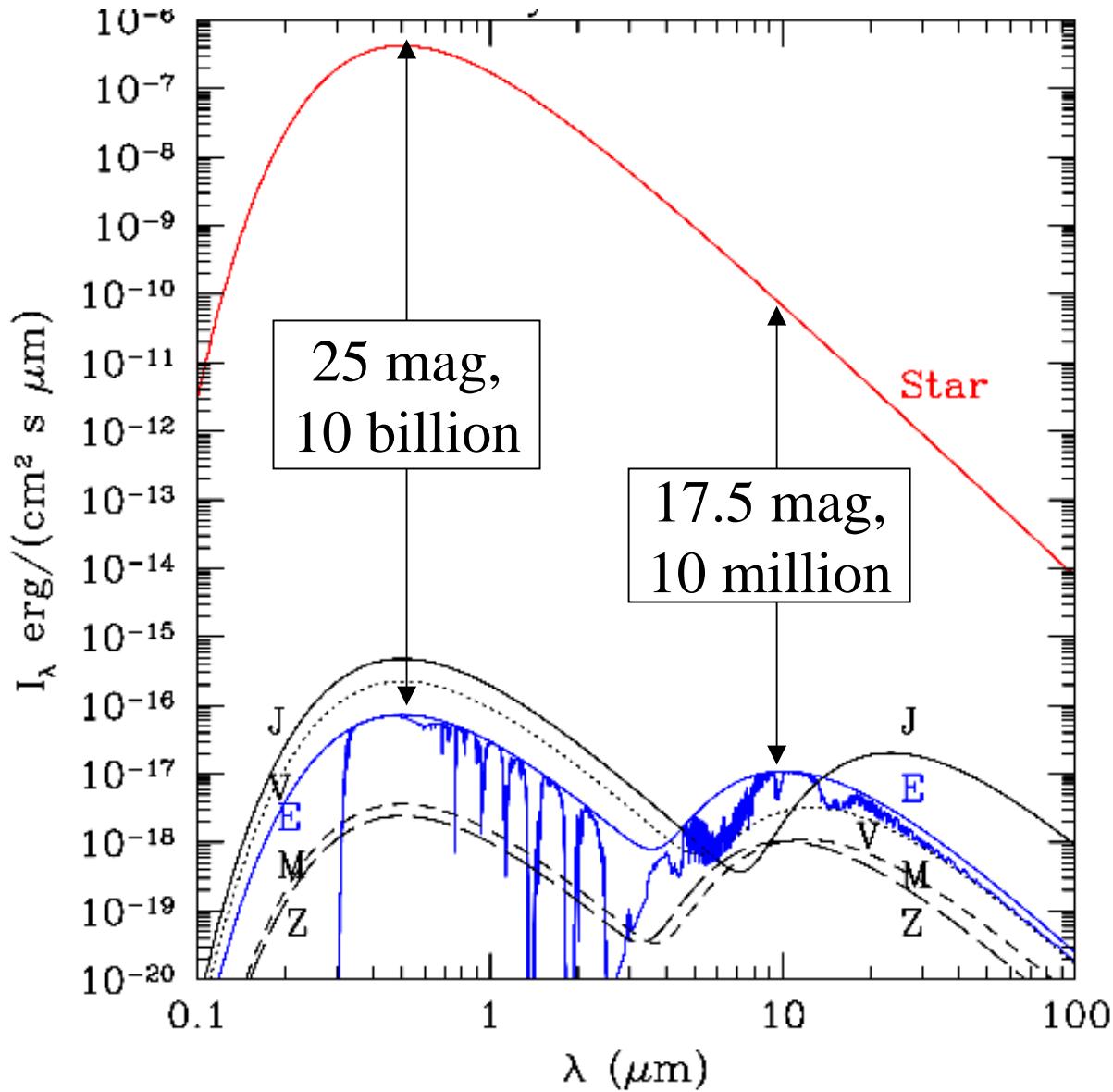
- TPF-C = coronagraph, ~6x4-m mirror
 - 2014 launch
 - NASA only, at present
-
- TPF-I / DARWIN = interferometer, ~3 free-flyers
 - 2015 - 2019 launch range
 - NASA-ESA collaboration

TPF Goals

- Detect and characterize **Terrestrial planets**, including a search for biomarkers
- Detect and characterize **planetary systems**, including giant planets and zodi disks
- Carry out **general astrophysics** investigations

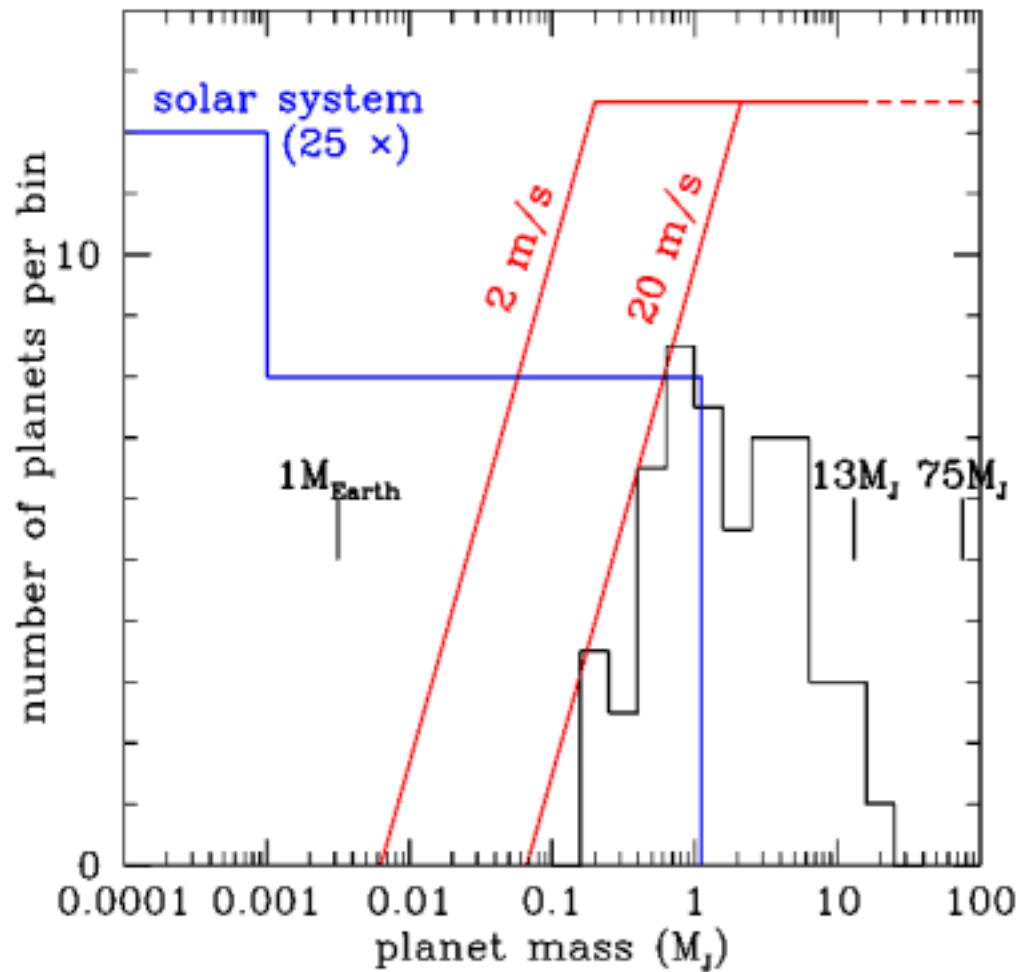
Solar system at 10 pc

- **Visible**
- **Earth/sun** $\sim 10^{-10}$
- **Infrared**
- **Earth/sun** $\sim 10^{-7}$

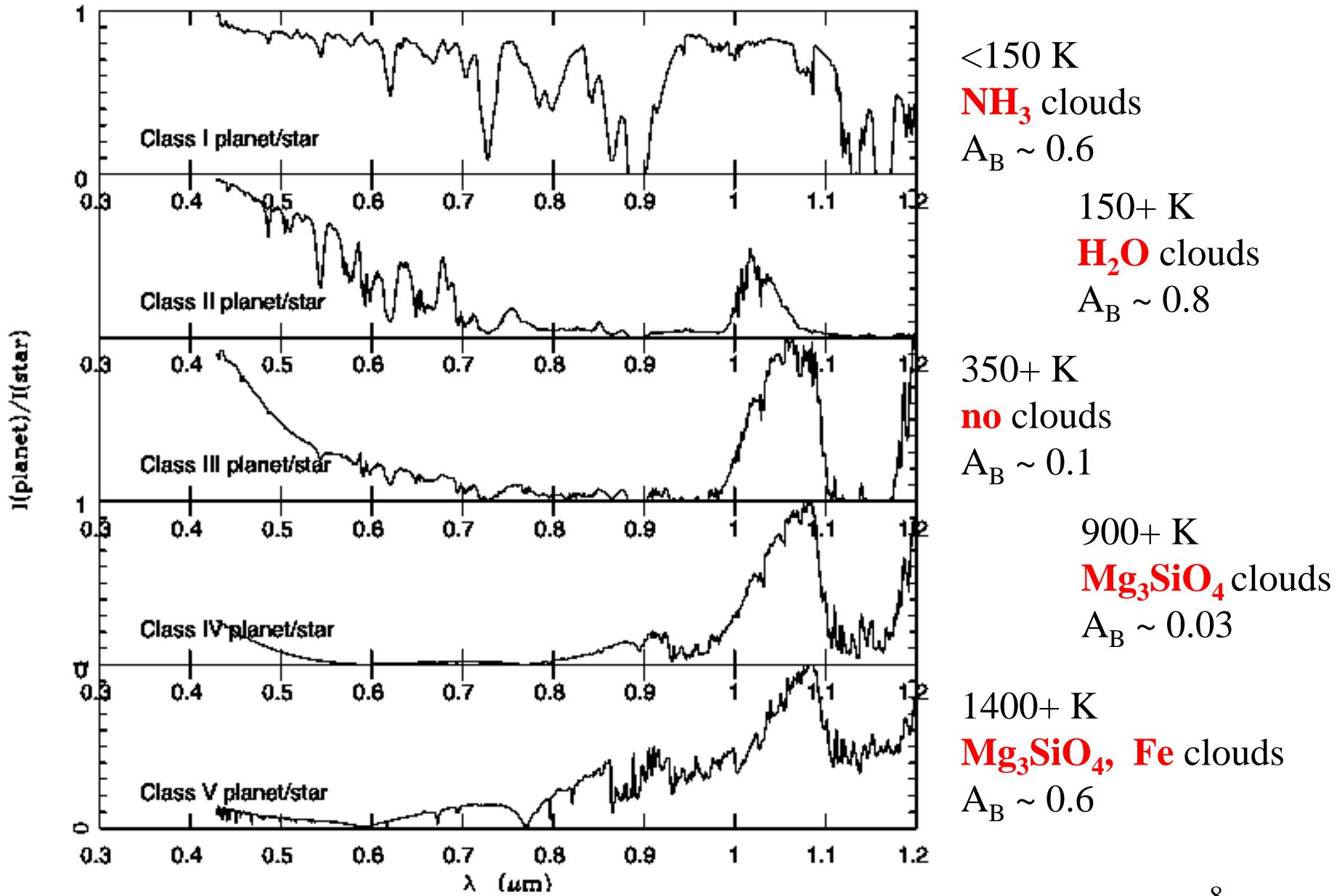


Mass distribution function (from known solar & extrasolar planets)

- Extrasolar planets
- Radial velocity cutoff
- Solar system
- Working hypothesis is $\eta_{\text{Earth}} \sim 10\%$

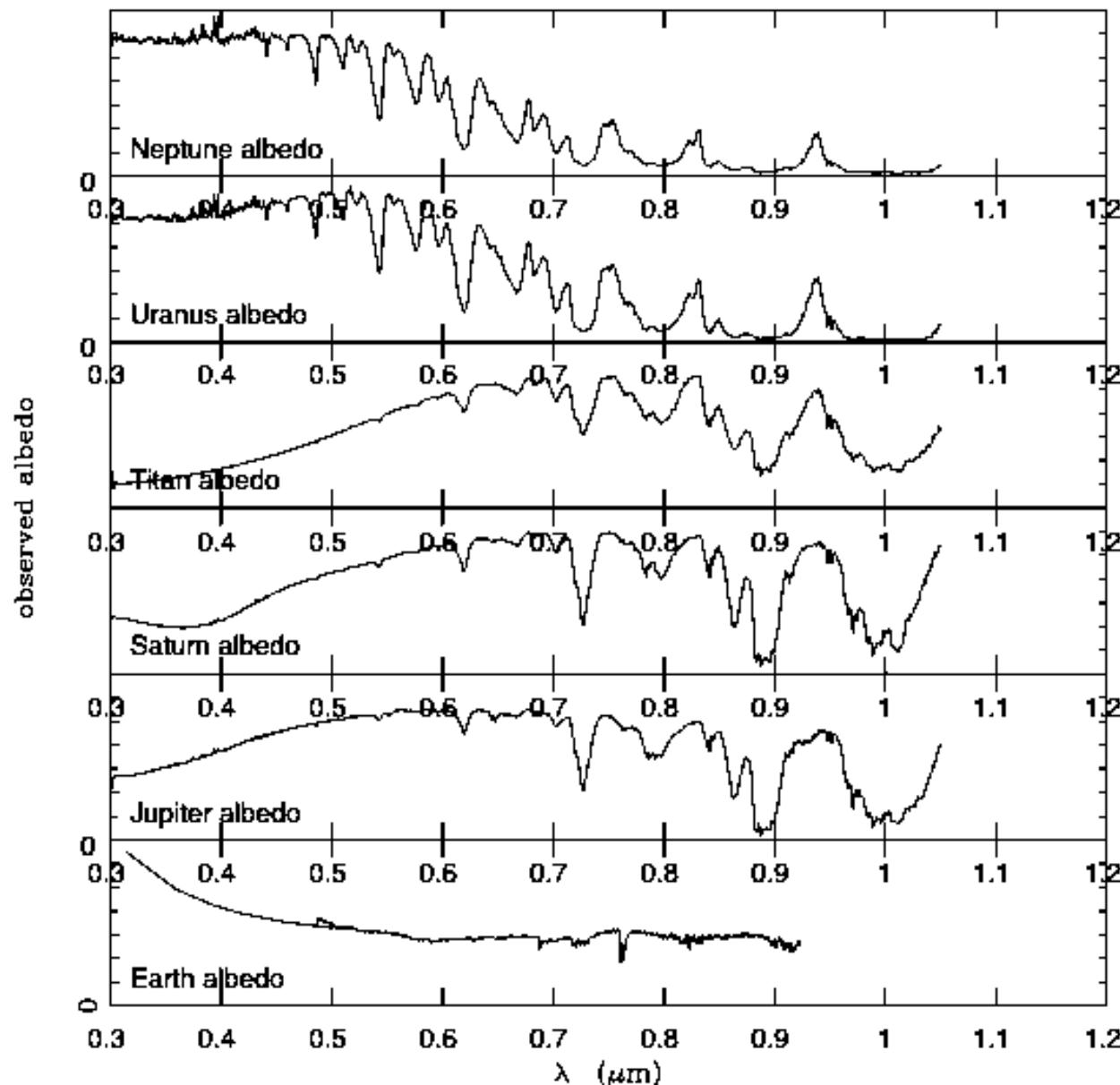


Class I-V Giant Planet Albedos



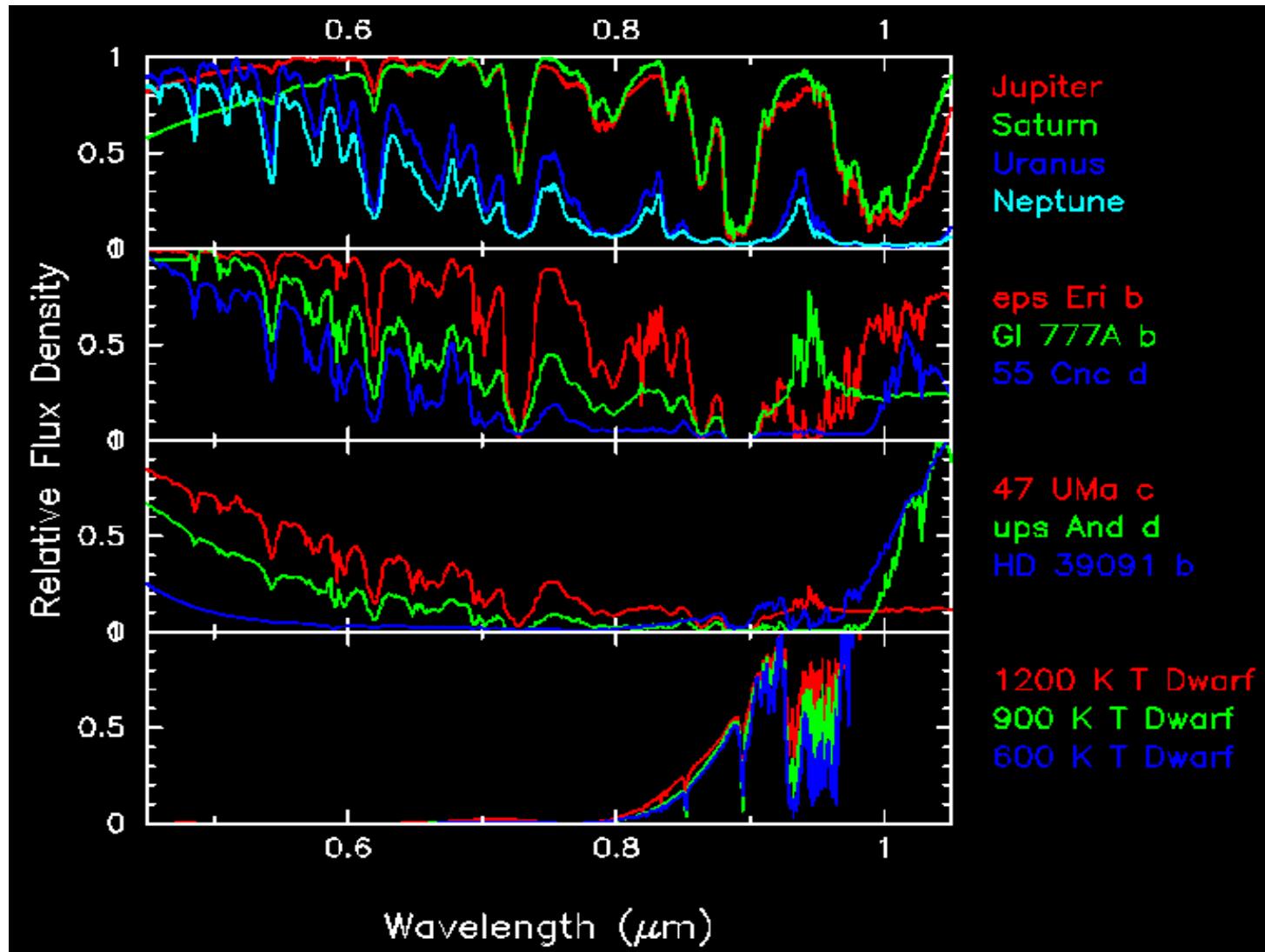
- Ref: Adam Burrows et al models.

Outer Planet and Earth Albedos (Measured)



- Ref. Karkoschka

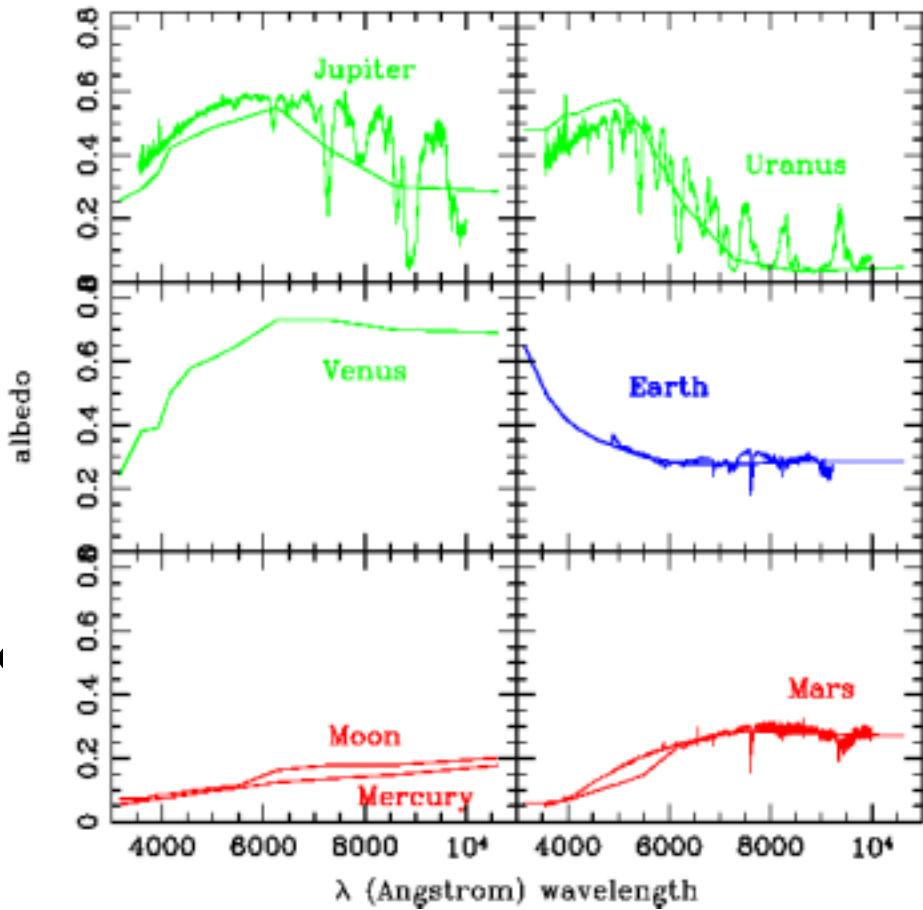
RV planets: model spectra



Color Implies: Mass, Radius, Temperature, and Atmospheric Pressure

4 planetary spectral types:

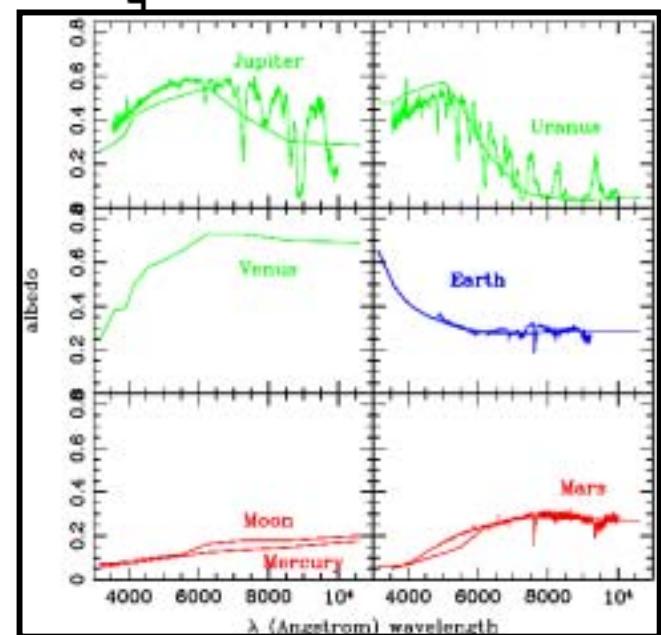
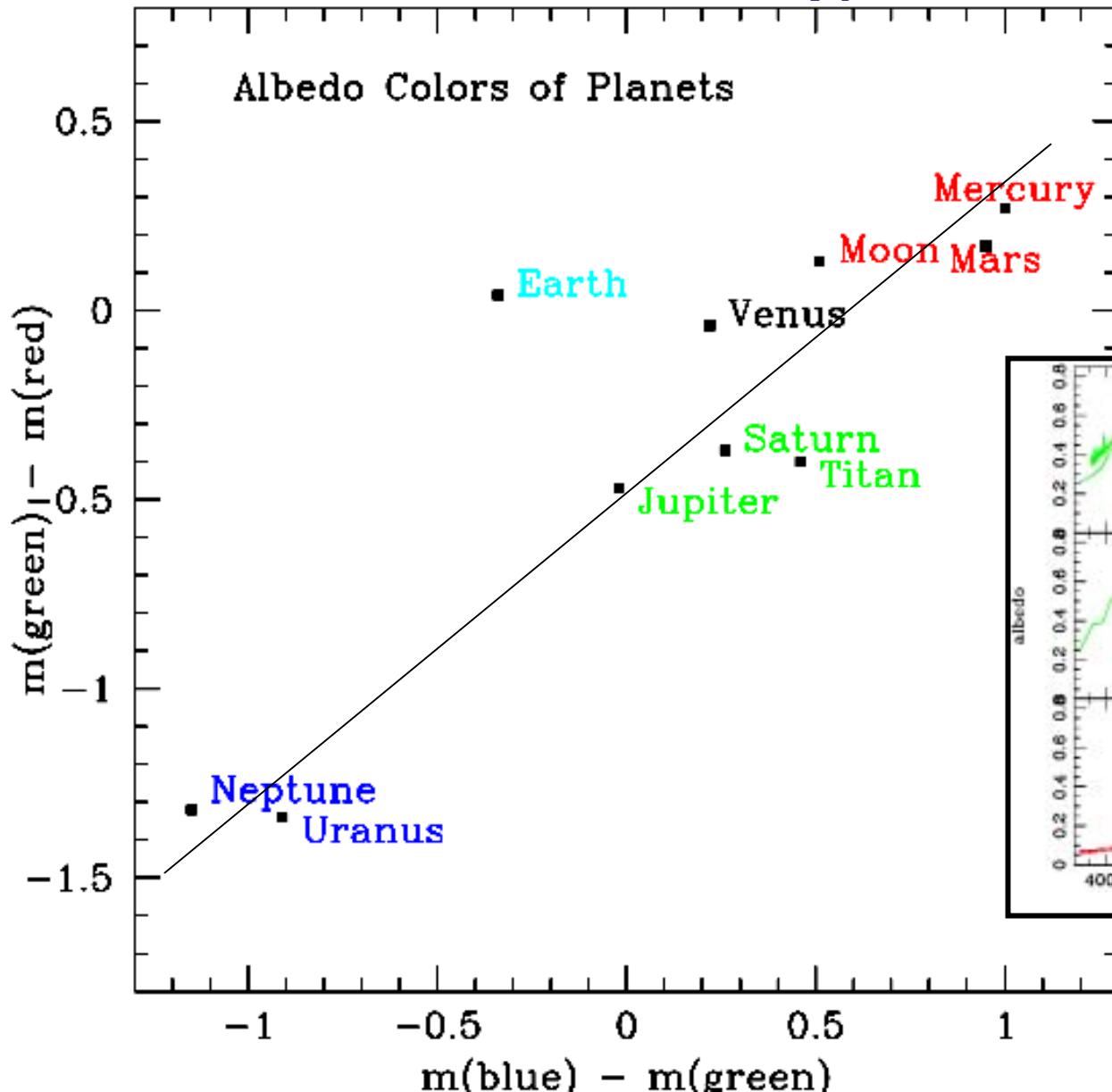
- Gas giant (Jupiter, Saturn, ...)
- Rocky (Mars, Mercury, Moon)
- Habitable (Earth)
- Greenhouse (Venus)



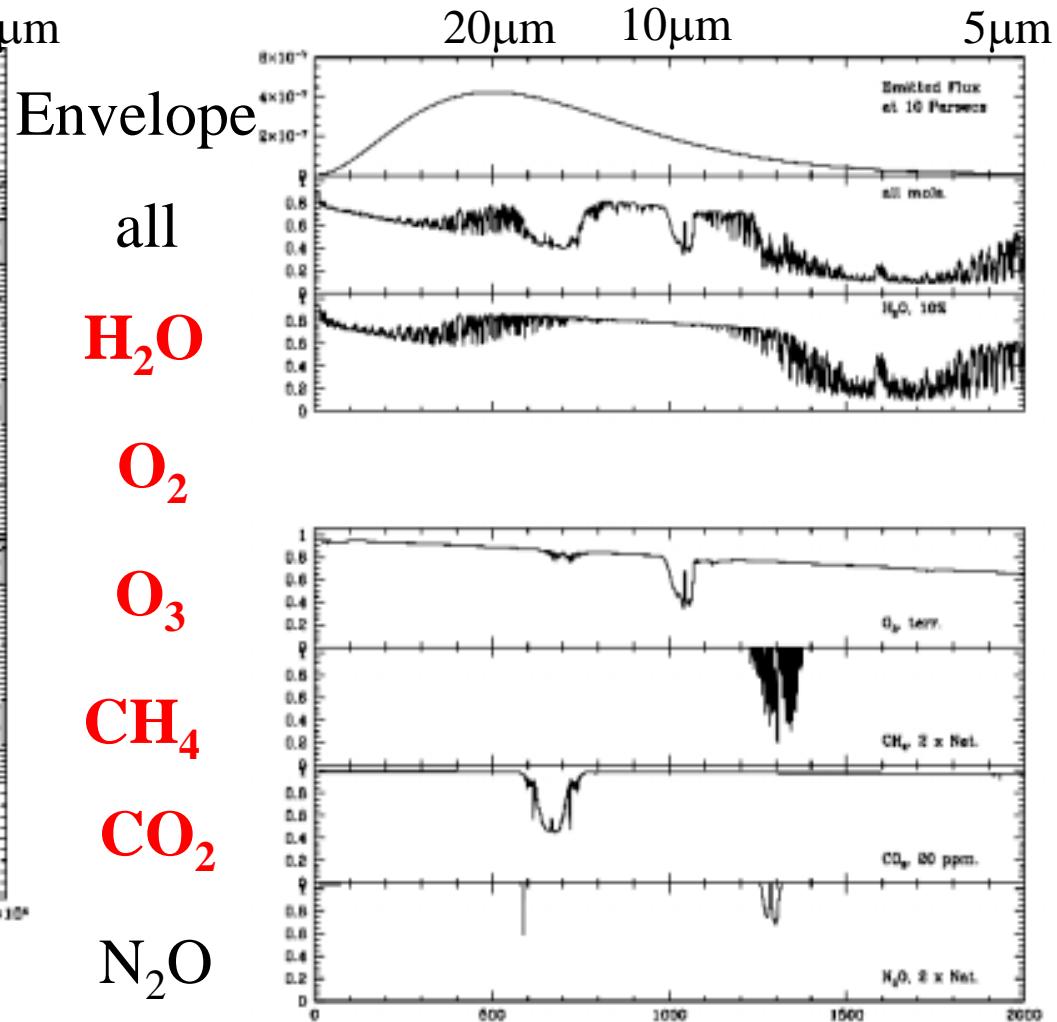
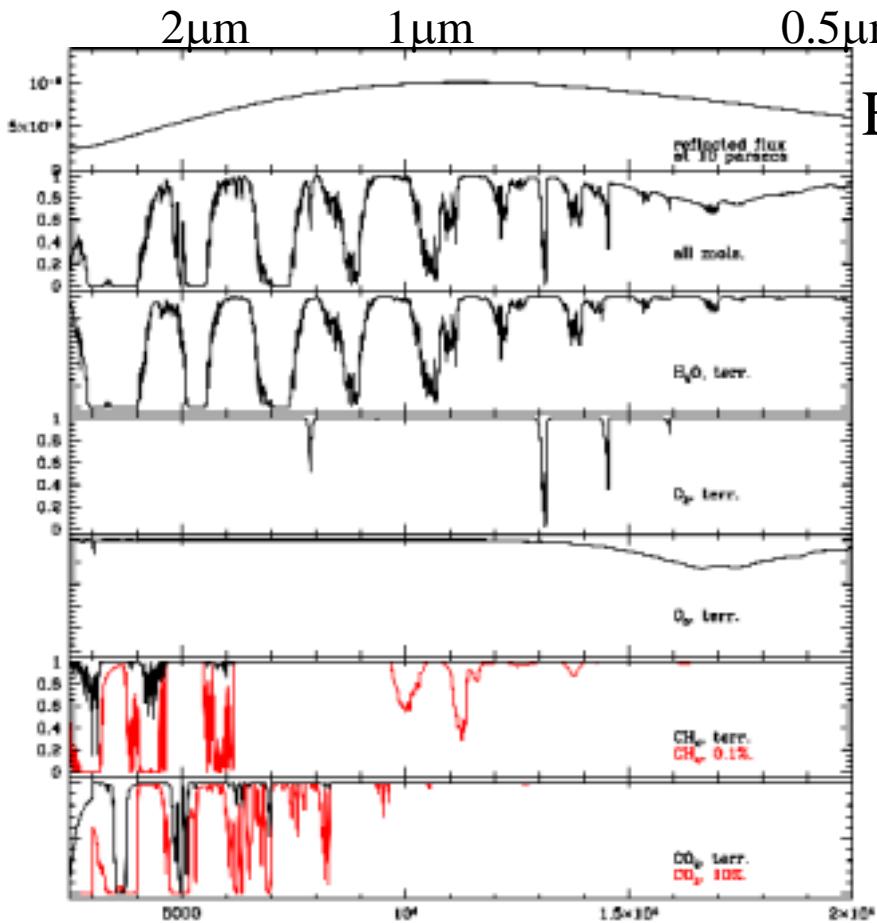
Spectral type (color) and magnitude of planet give:

- Radius
- Mass (implies atmospheric retention and plate tectonics)
- Effective temperature
- Atmospheric pressure

Color-color Diagram of Planets



Molecule-by-molecule spectra



Refs: Traub & Jucks, AGU Geophys. Monograph 130, 2002;
Des Marais et al, Astrobiology 2 153 2002.

no life : life atmospheric abundances

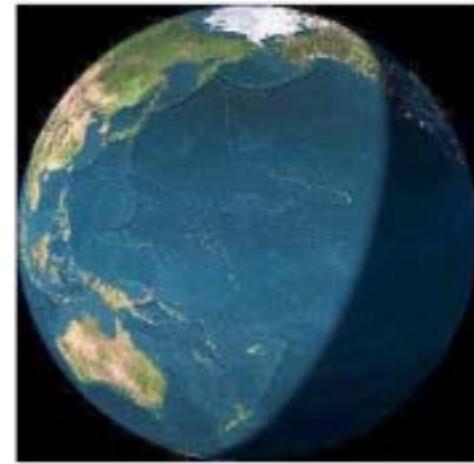
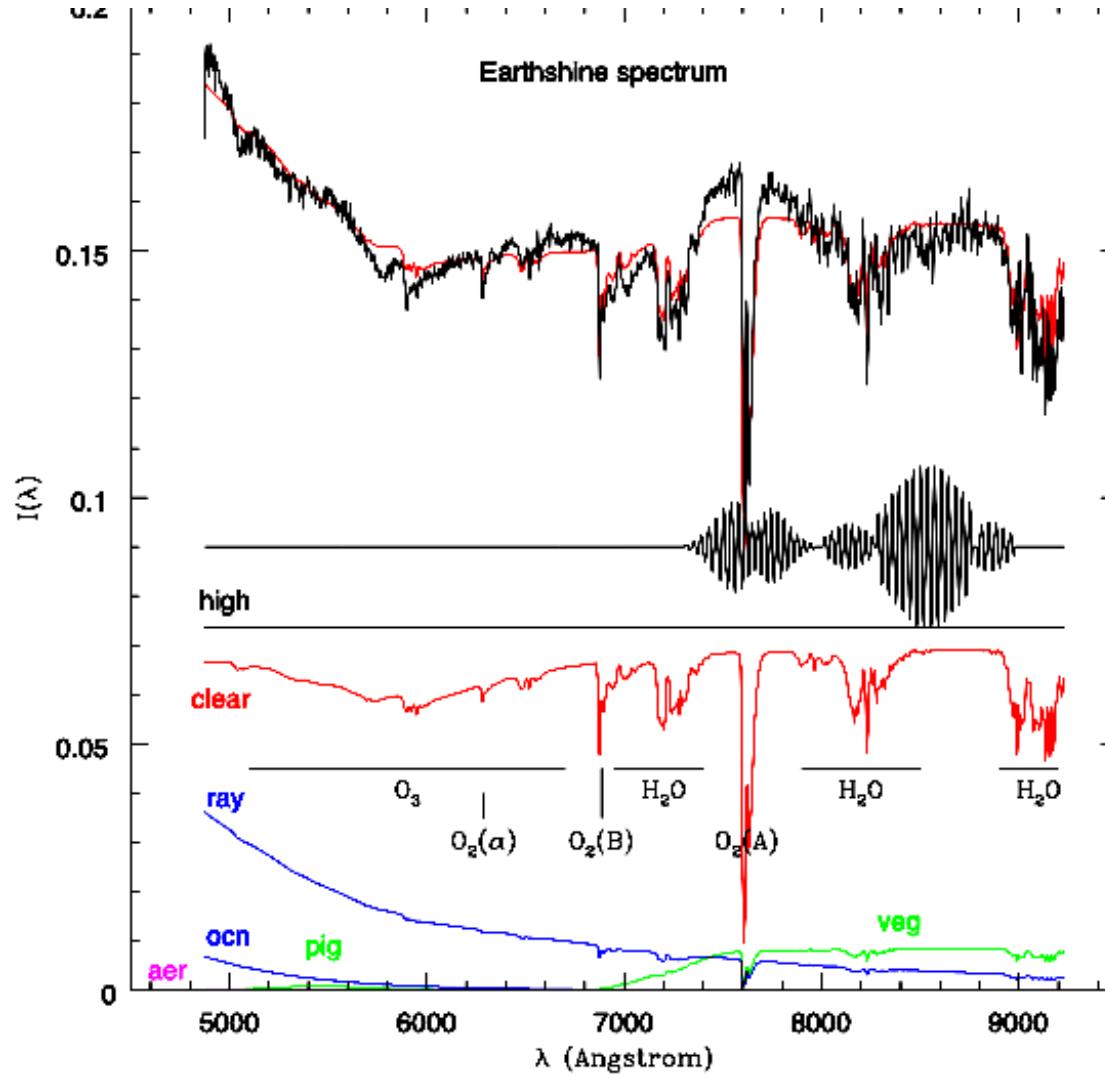
Gas	no life : life
• O ₂	1 : 100
• N ₂ O	1 : 100
• CH ₄	1 : 1,000
• CO ₂	1 : 0.001

Order-of-magnitude values.

Other gases not readily detectable: H₂, NH₃, HCl, CO, N₂

Refs: Rambler 1989; Margulis & Lovelock 1974; Yung & DeMore 1999

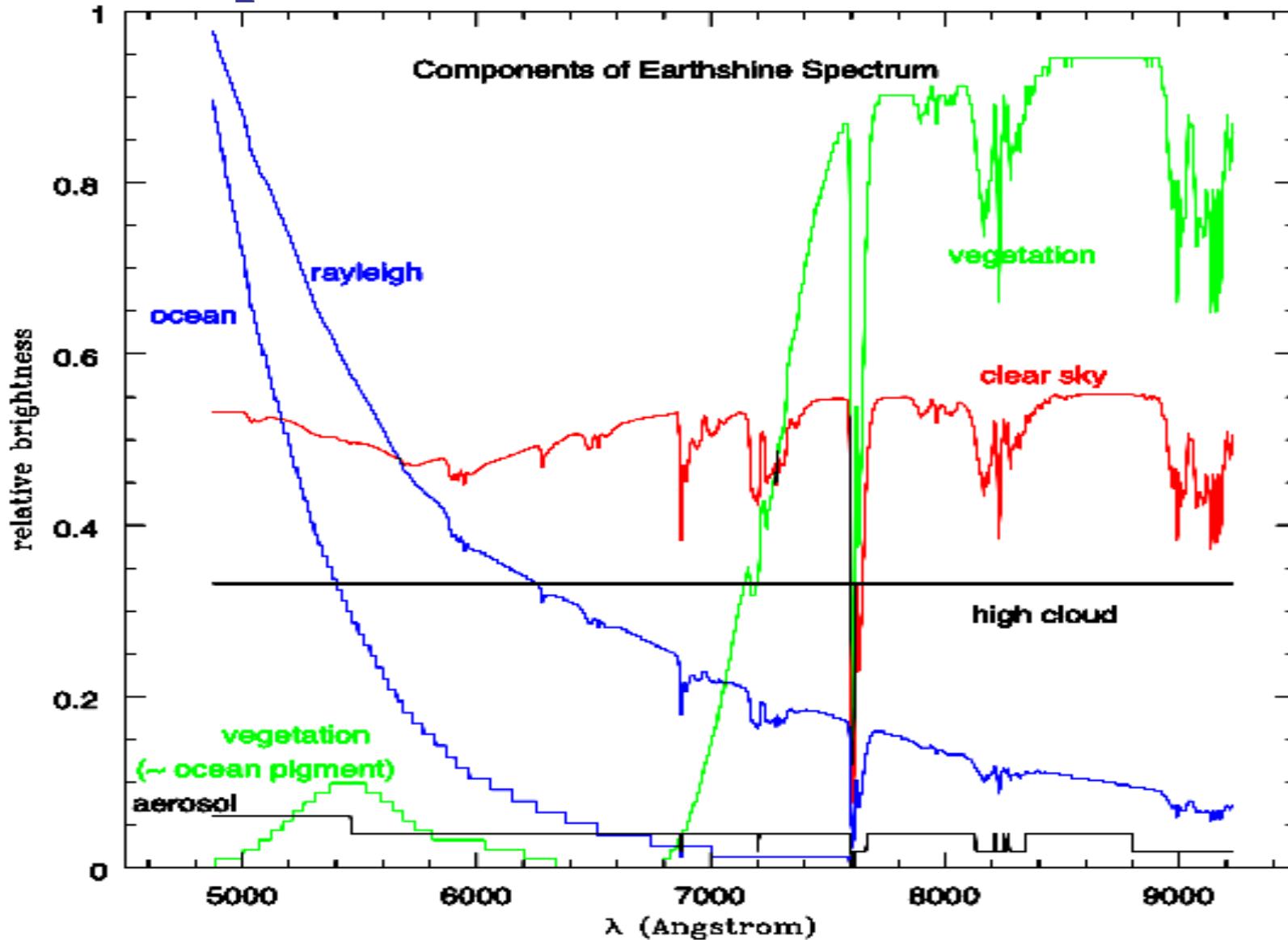
Earthshine: visible spectrum



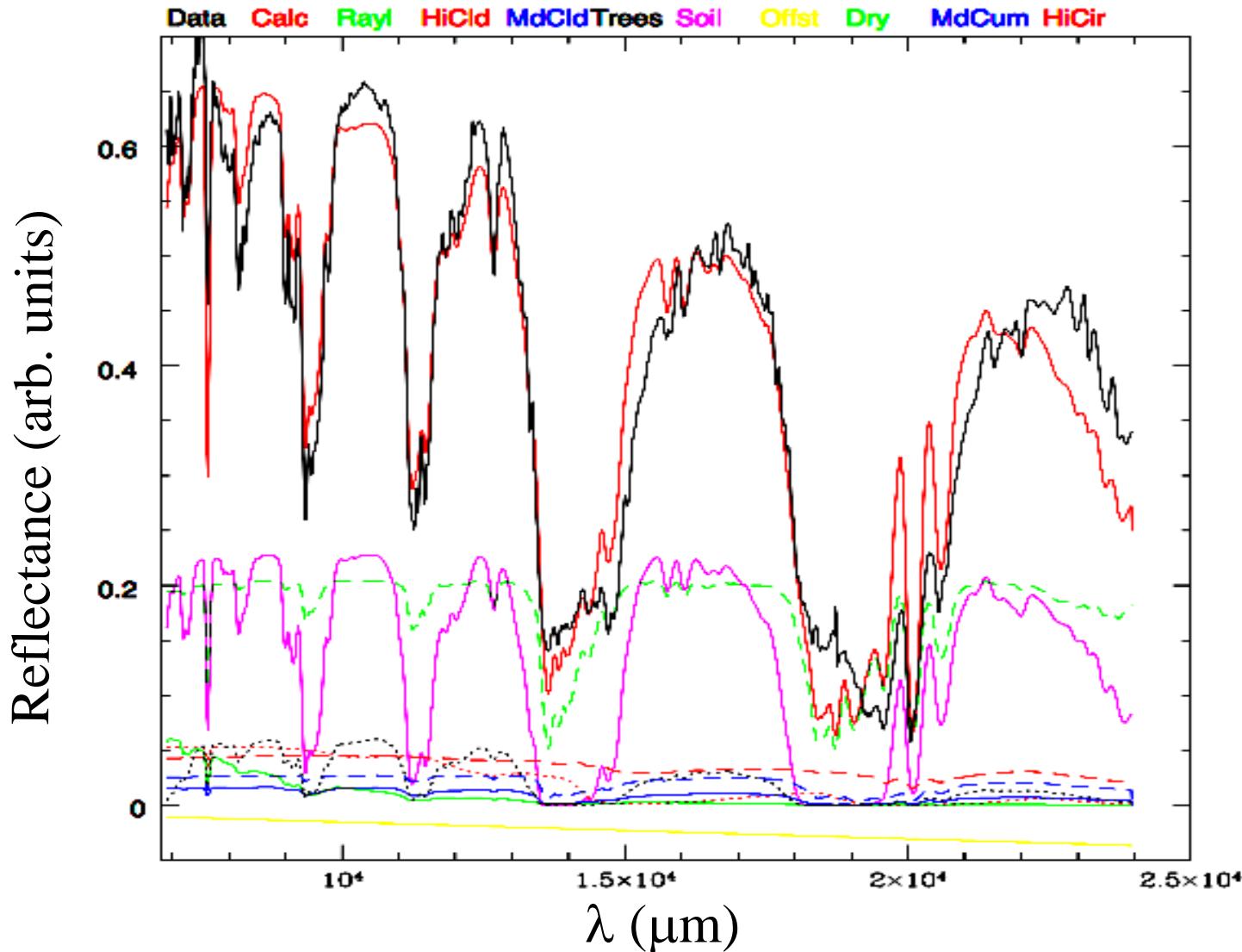
- Integrated light of Earth, reflected from dark side of moon; Rayleigh, chlorophyll, O₂, O₃, H₂O.

Ref.: Woolf, Smith, Traub, & Jucks, ApJ 2002; also Arnold et al. 2002

Components of Box Model of Earthshine

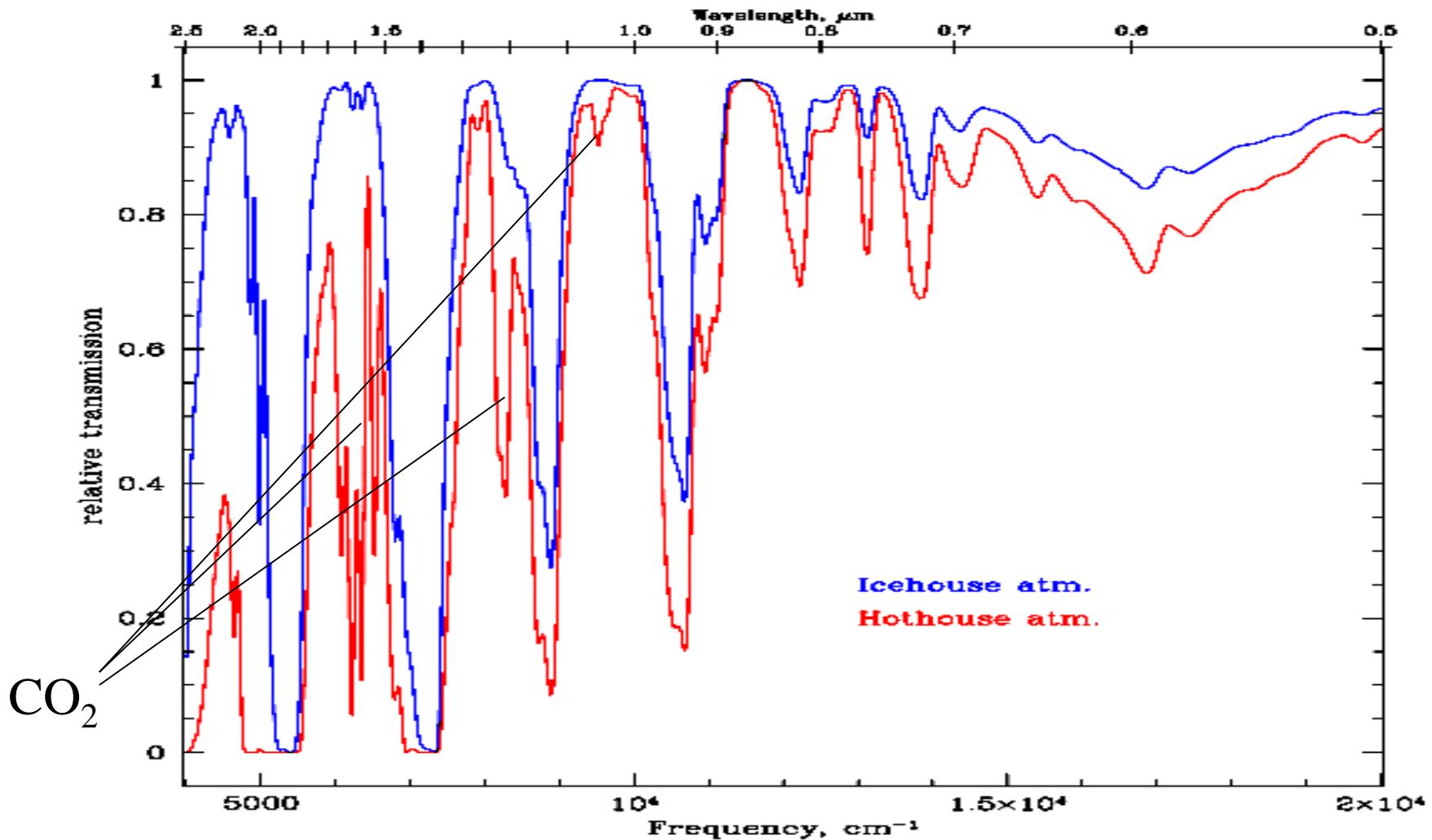


Earthshine in near-infrared: 0.7-2.4 μ m



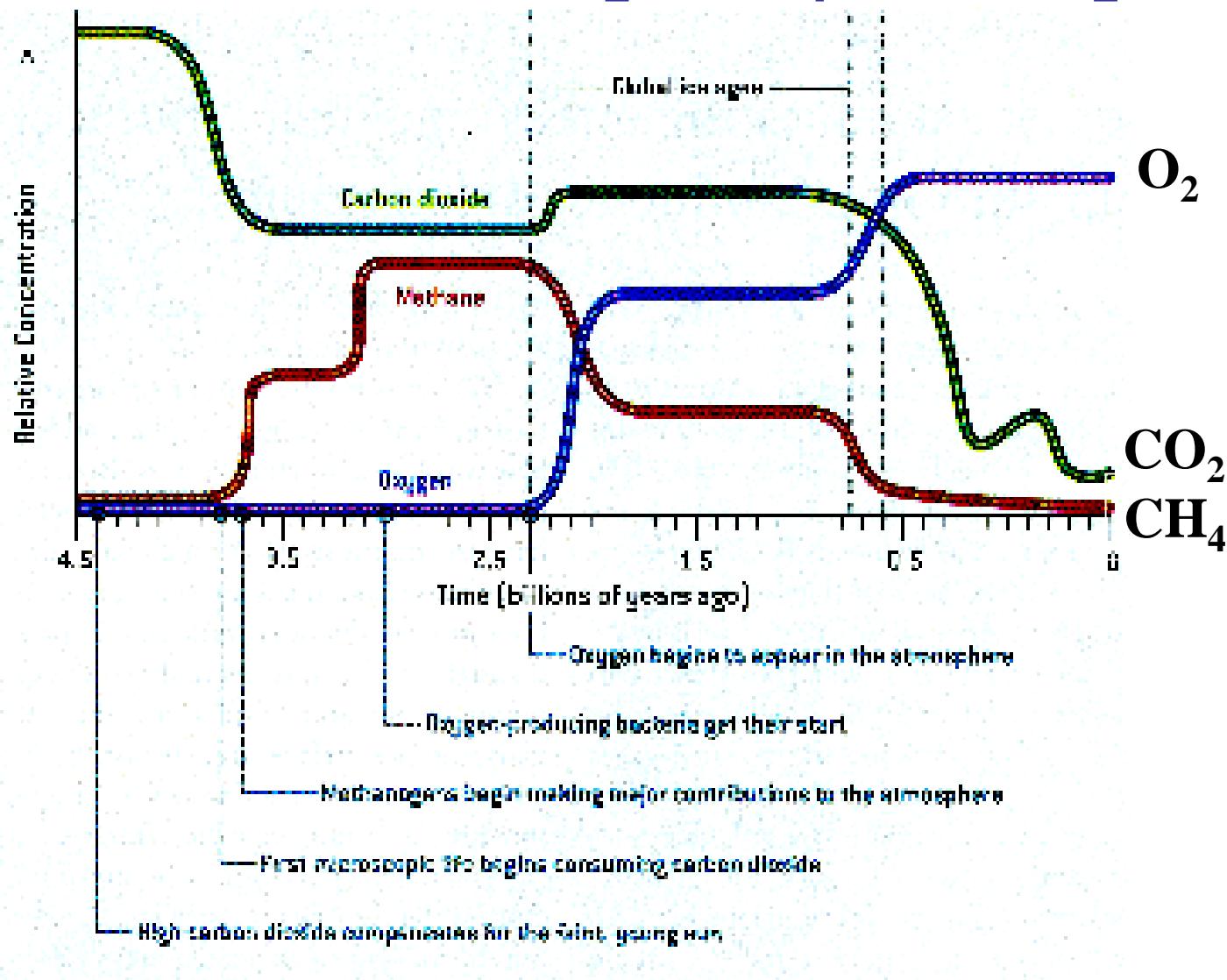
Spectrum is sensitive to mix of dry land, humid land, & cloud types.

Neoproterozoic Earth

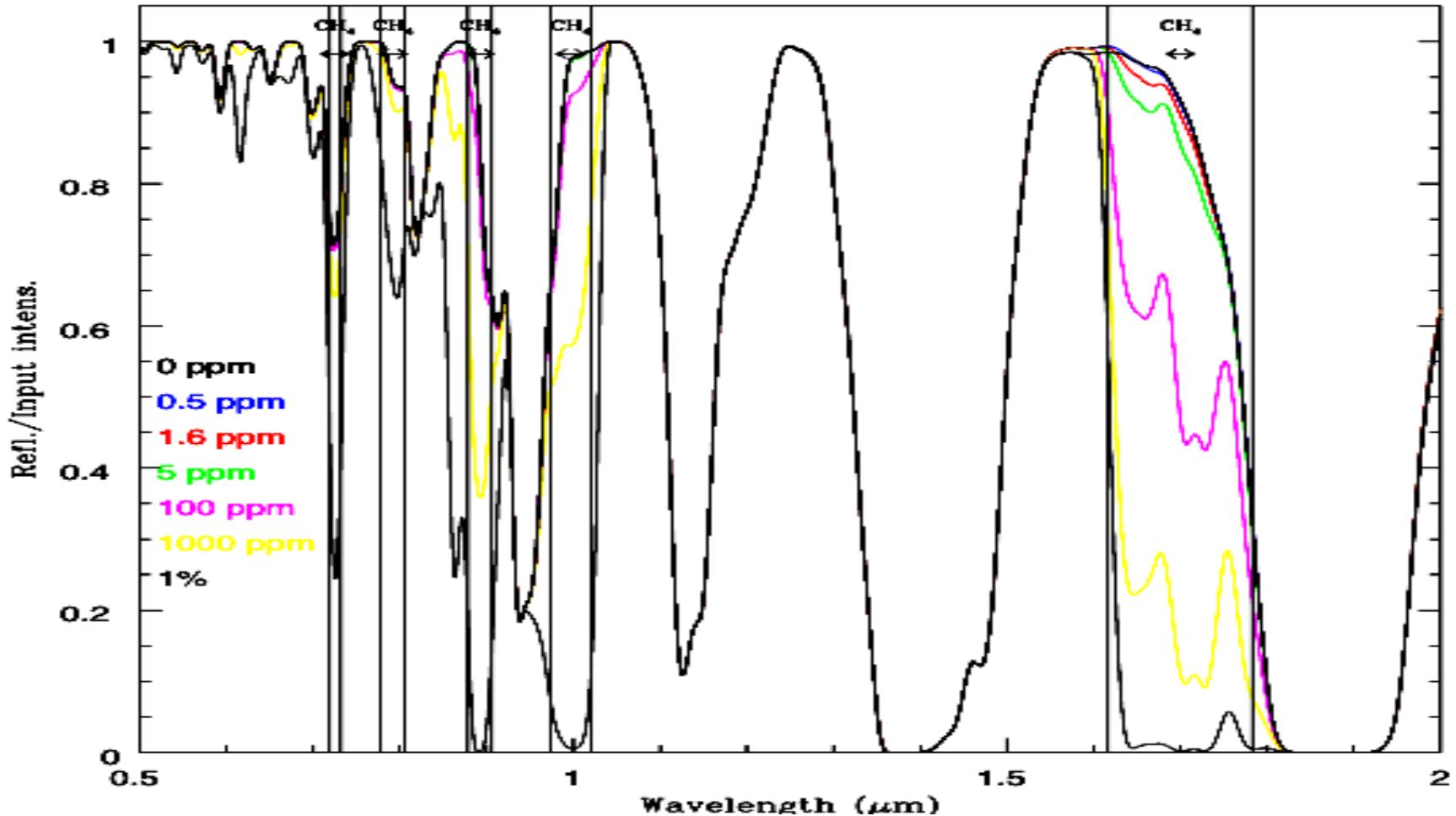


- Oscillations between icehouse & hothouse, ~0.7 Gyr ago

Early Earth CO_2 , CH_4 , and O_2

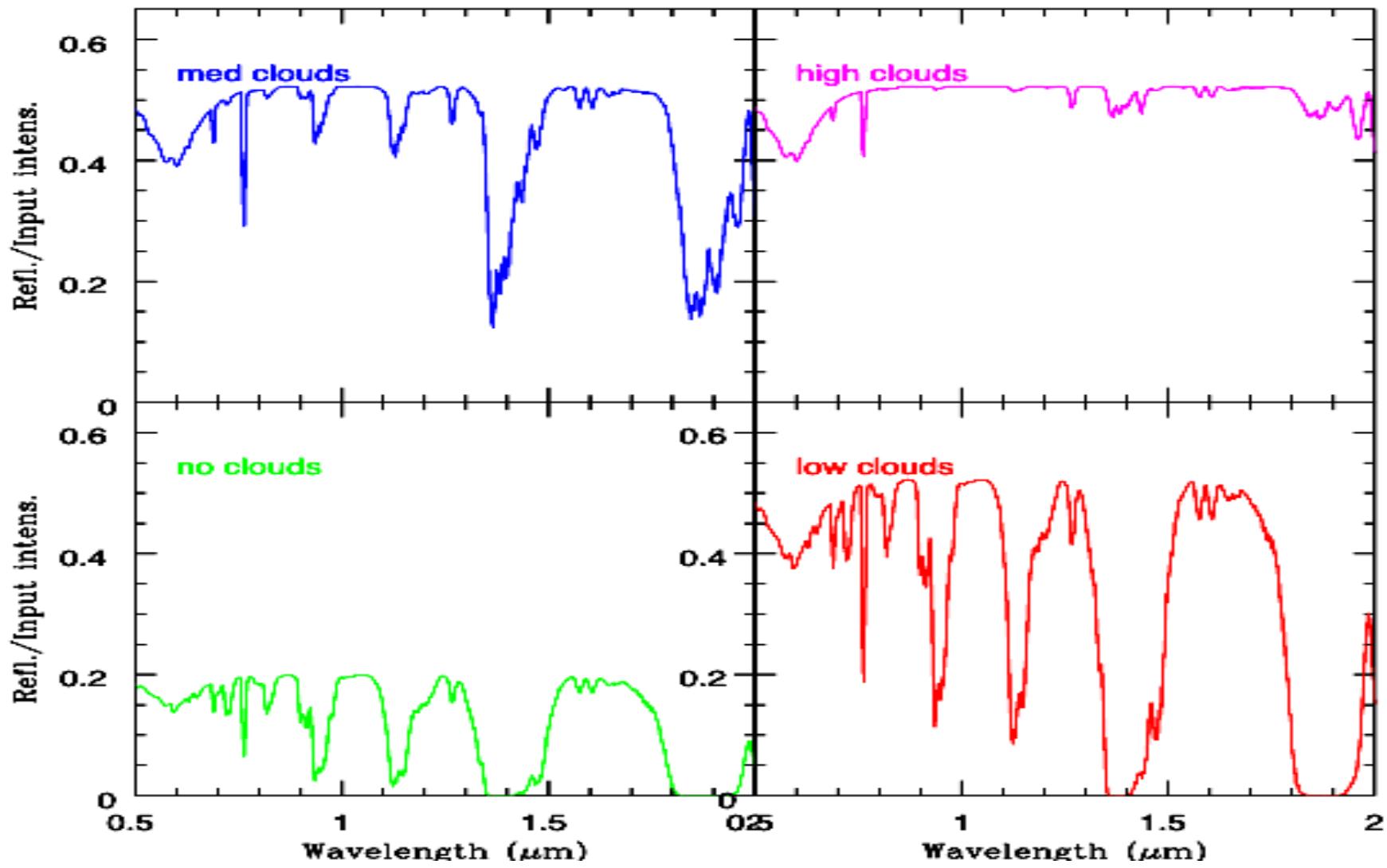


CH_4 Visible Spectrum

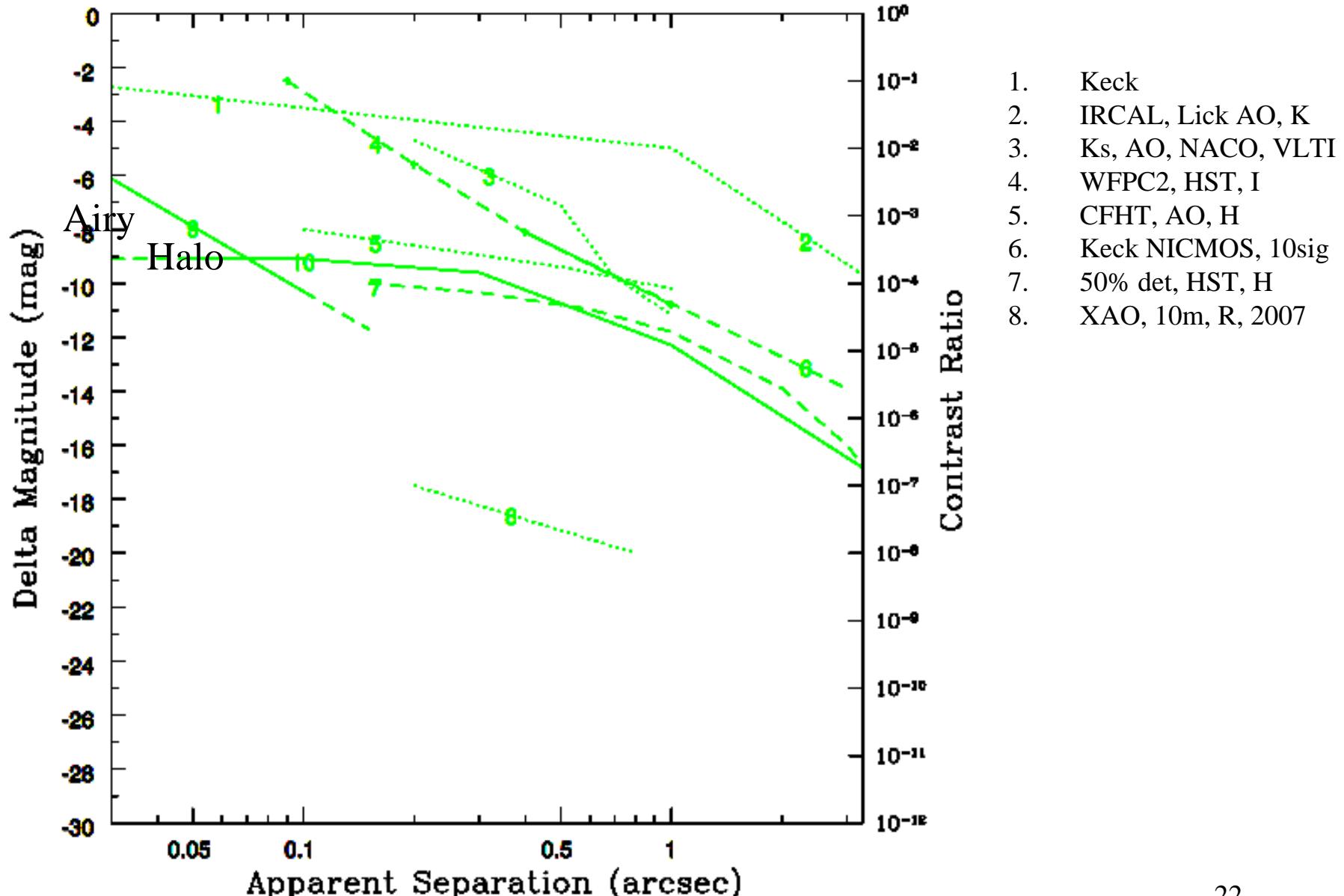


- Early Earth before rise of O_2 ~2.3 Gyr ago
- Methane hydrate burst ~0.2 and 0.06 Gyr ago

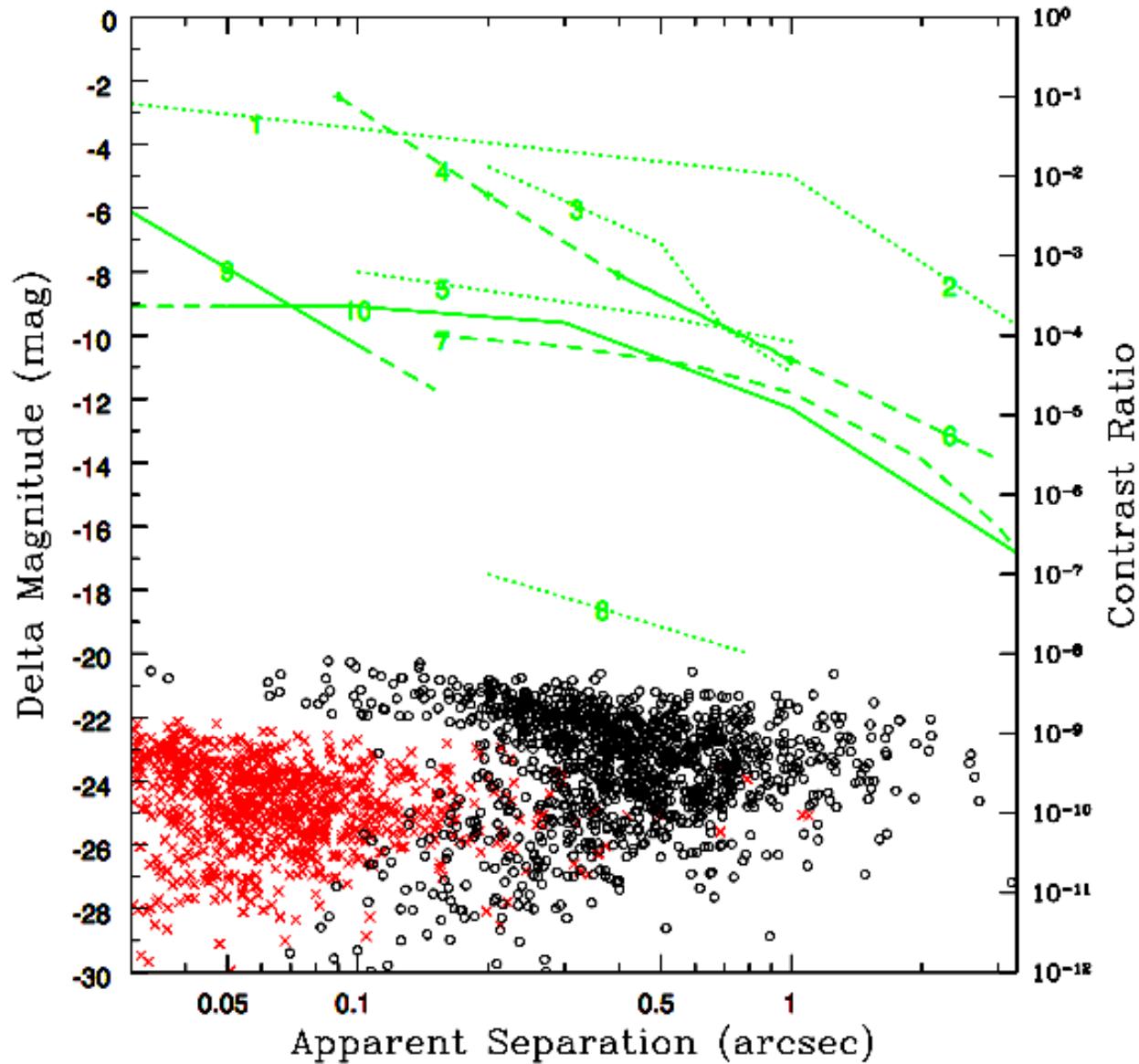
Effect of Cloud Cover



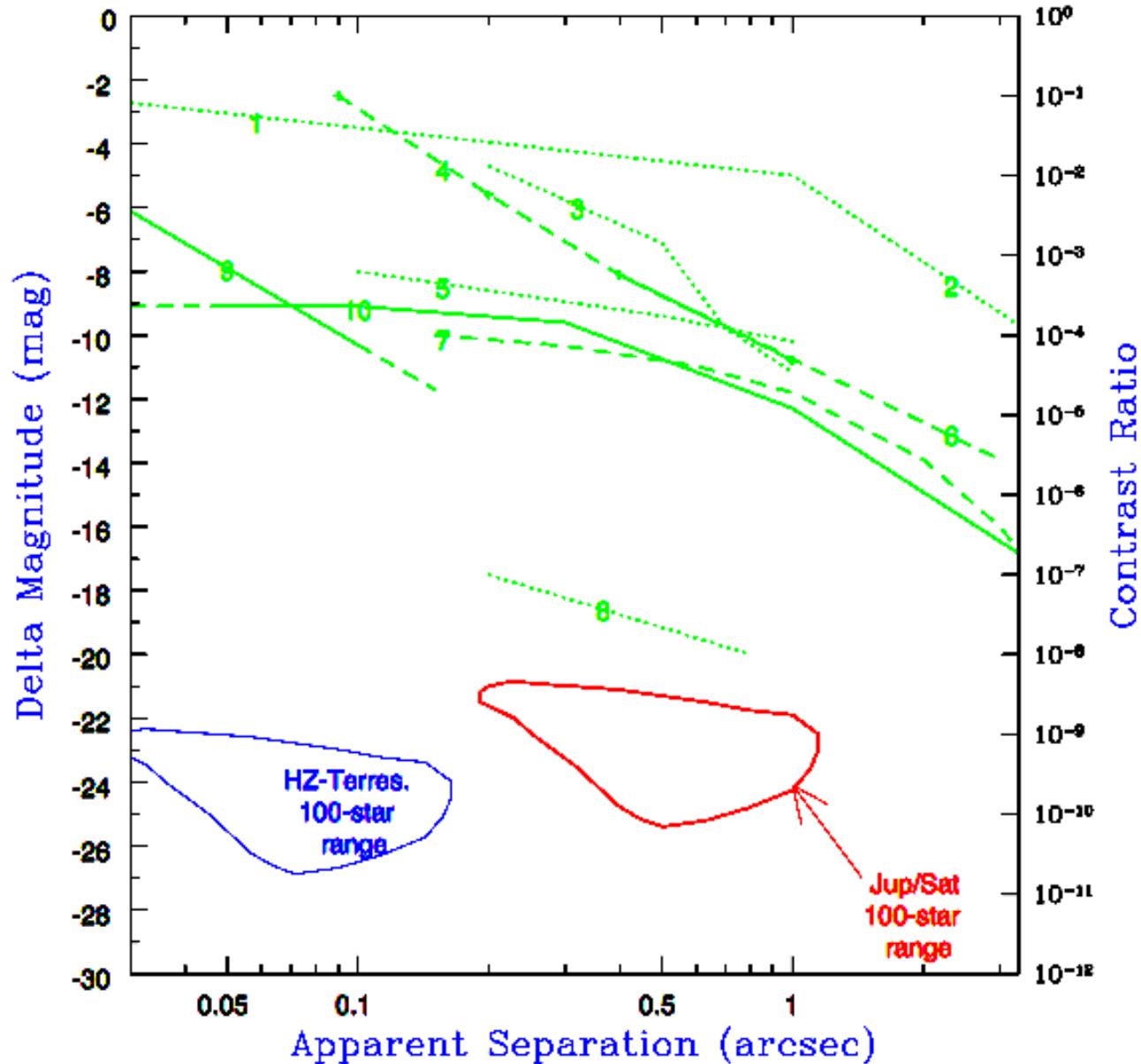
Coronagraph/AO search space: best to date



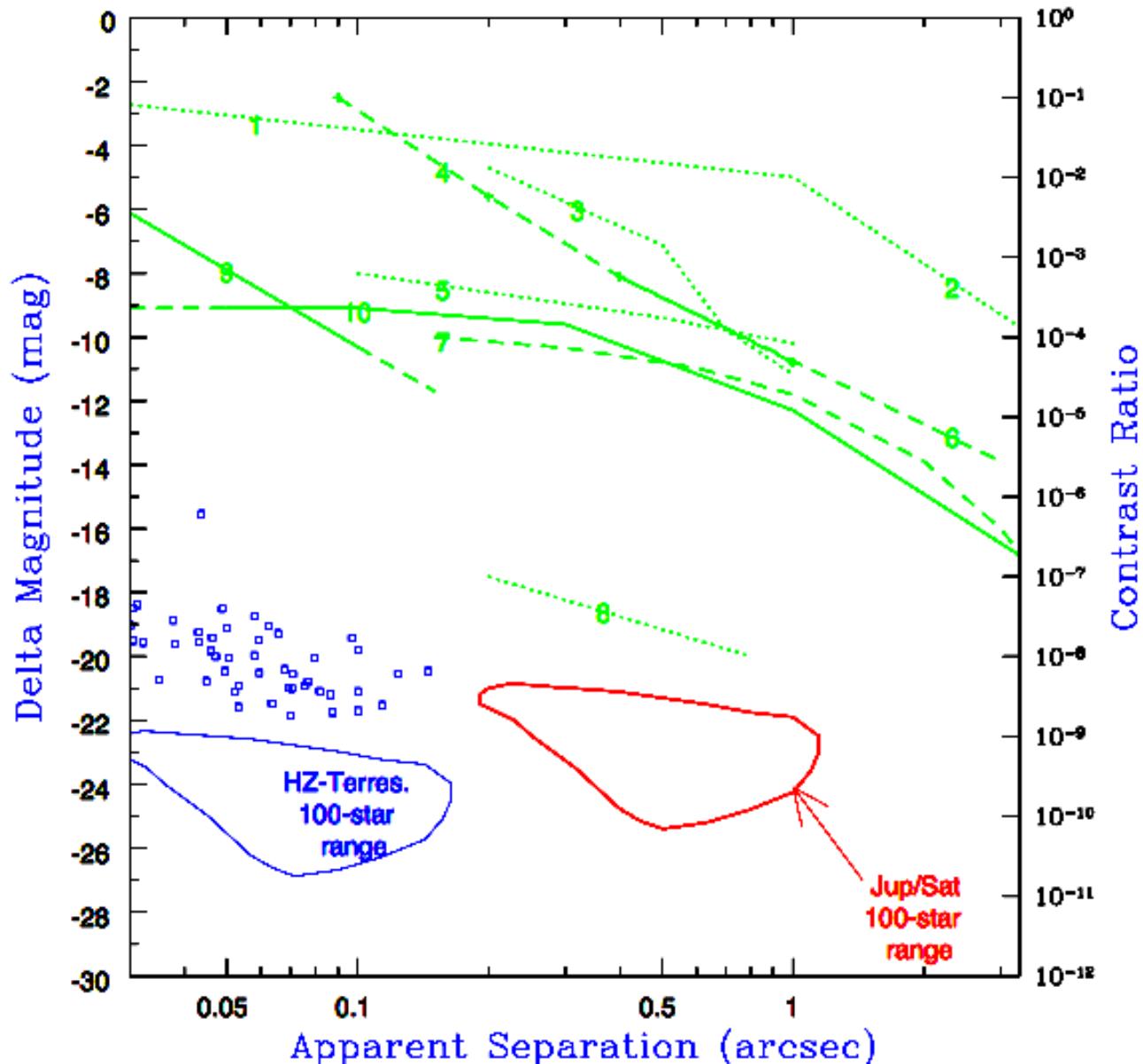
Earth & Jupiter-Saturn, 100 stars



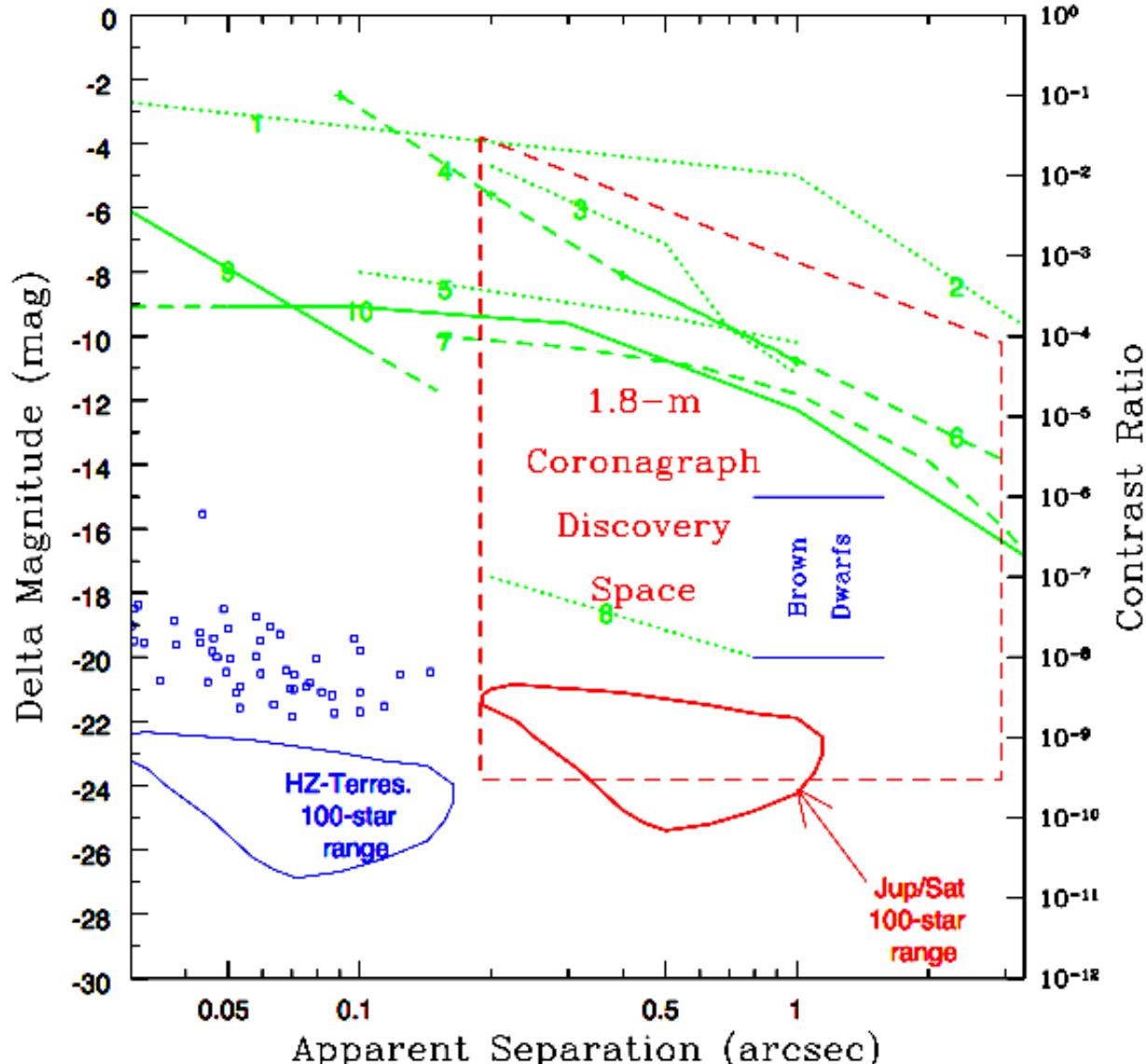
Earth & Jupiter-Saturn Regions



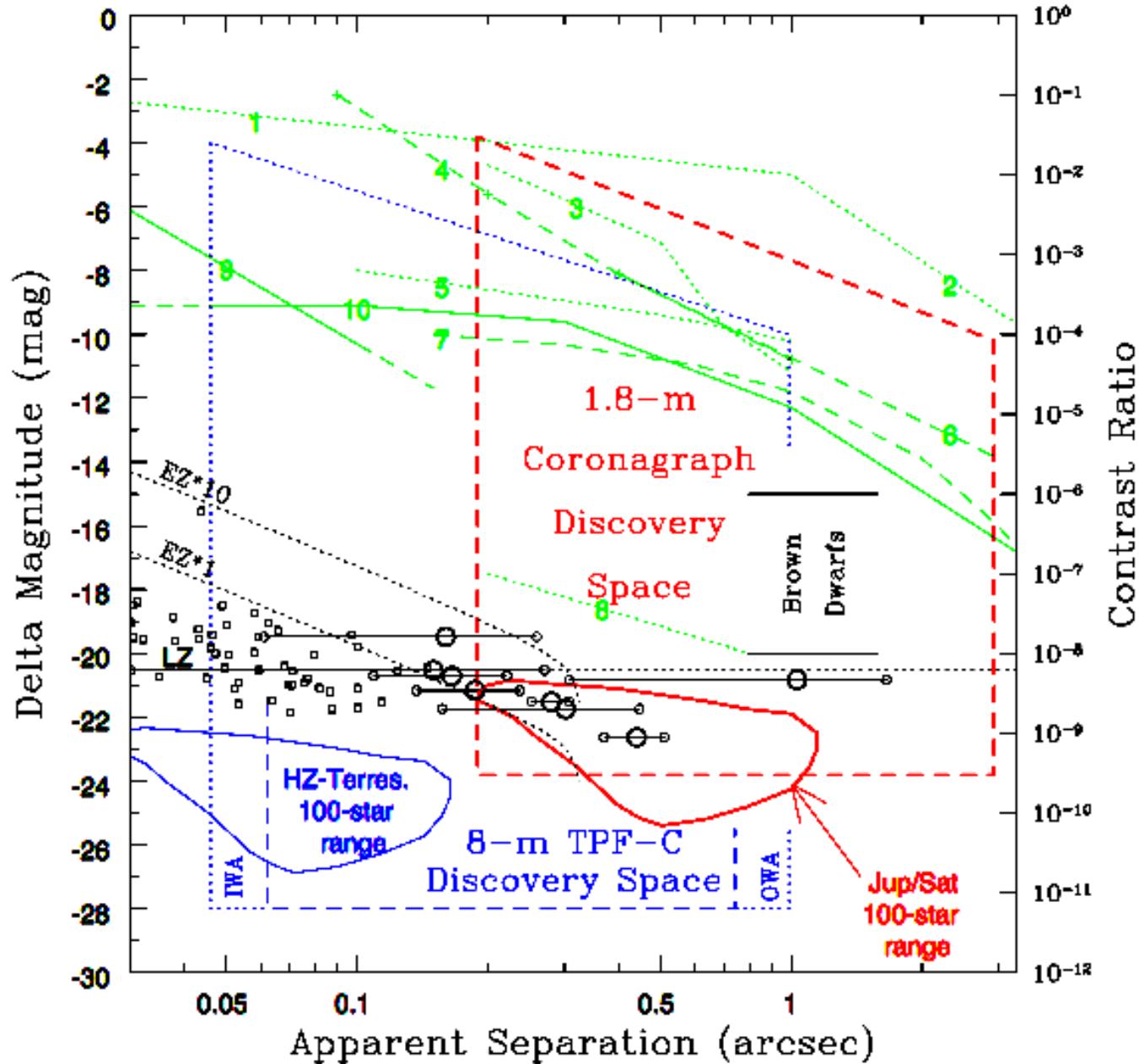
Radial-velocity Stars



1.8-m telescope



TPF-C and 1.8-m discovery spaces



C, IWA, OWA

Contrast C:

Example: $C = 10^{-10}$ driven by Earth/Sun = 2×10^{-10} .

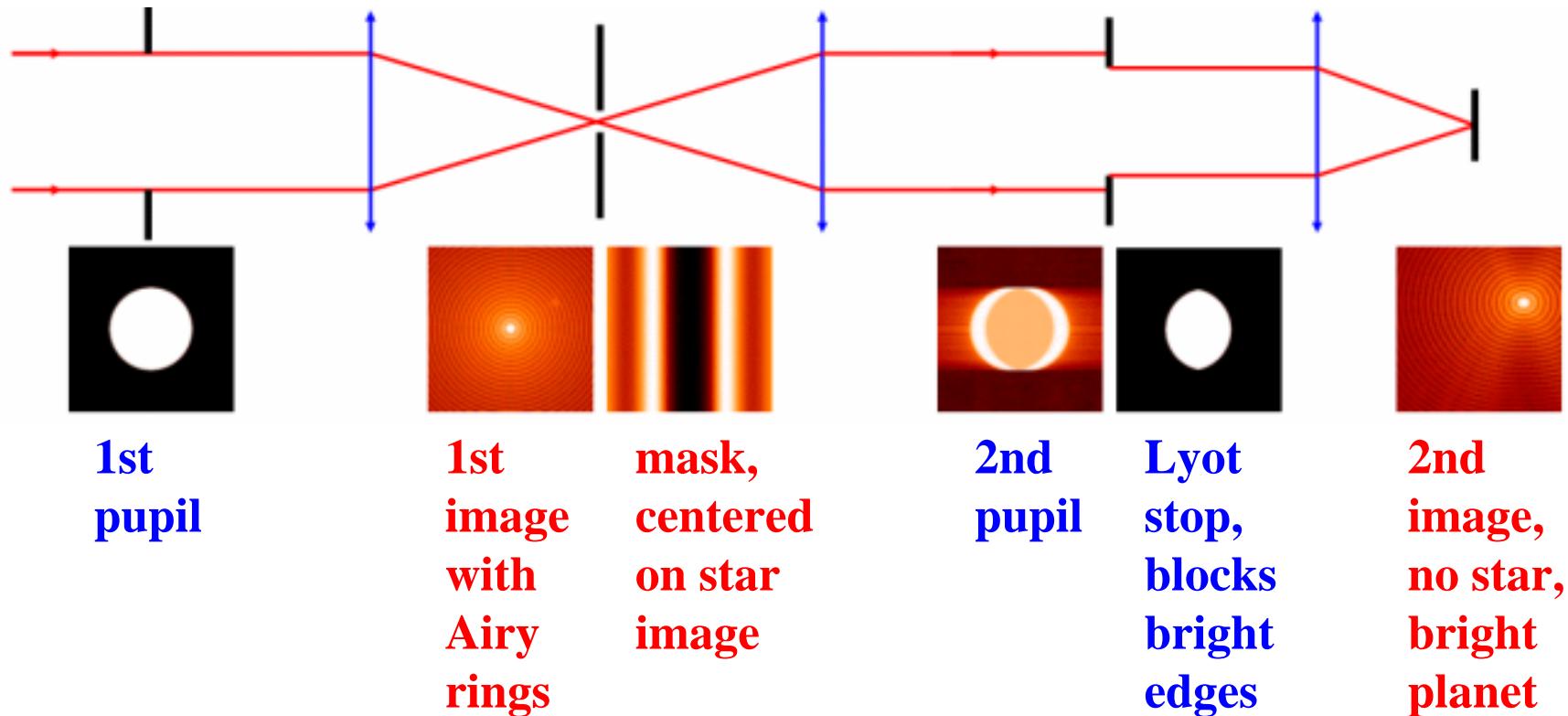
Inner working angle IWA:

Example: $IWA = 3 \lambda/D$ driven by 1 AU/10pc = **0.100 arcsec.**

Outer working angle OWA:

Example: $OWA = 48 \lambda/D$ driven by **N = 96 actuator DM.**

Image-plane coronagraph simulation



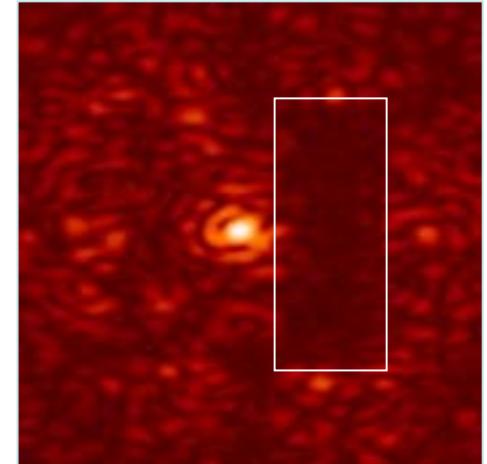
Measured
Airy rings,
Kasdin et al

Ref.: Pascal Borde 2004; mask is from Kuchner and Traub 2002.

Phase ripple and speckles

Polishing and reflectivity errors in pupil

Phase ripples from primary mirror errors



Speckles generated by 3 sinusoidal components of the polishing errors

No DM:

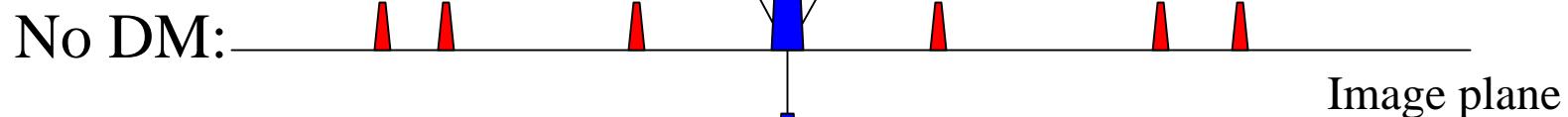


Image plane

With DM:

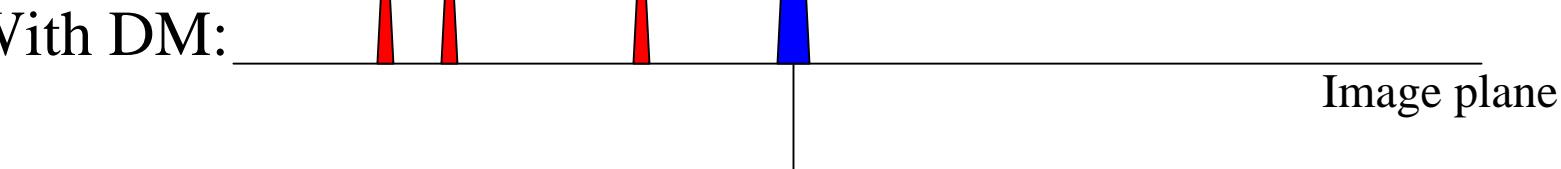
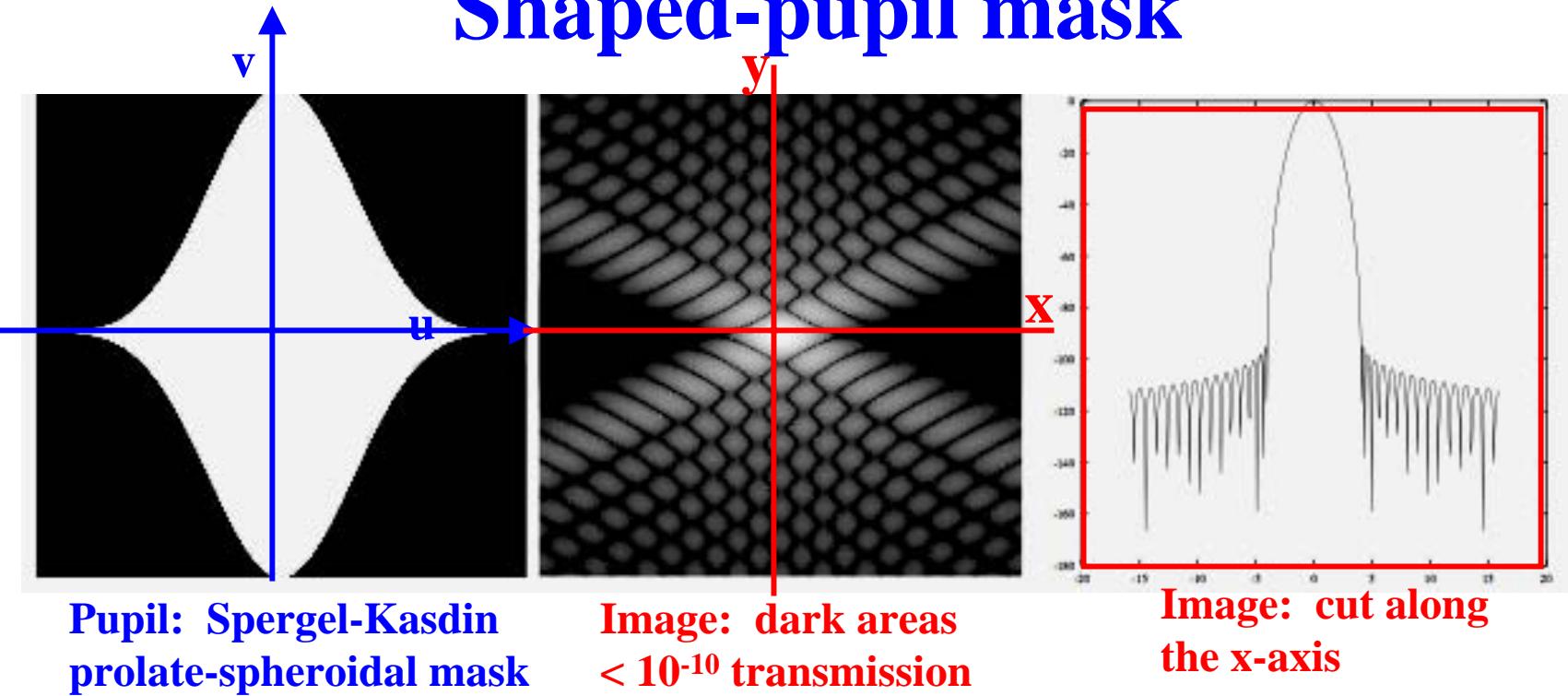


Image plane

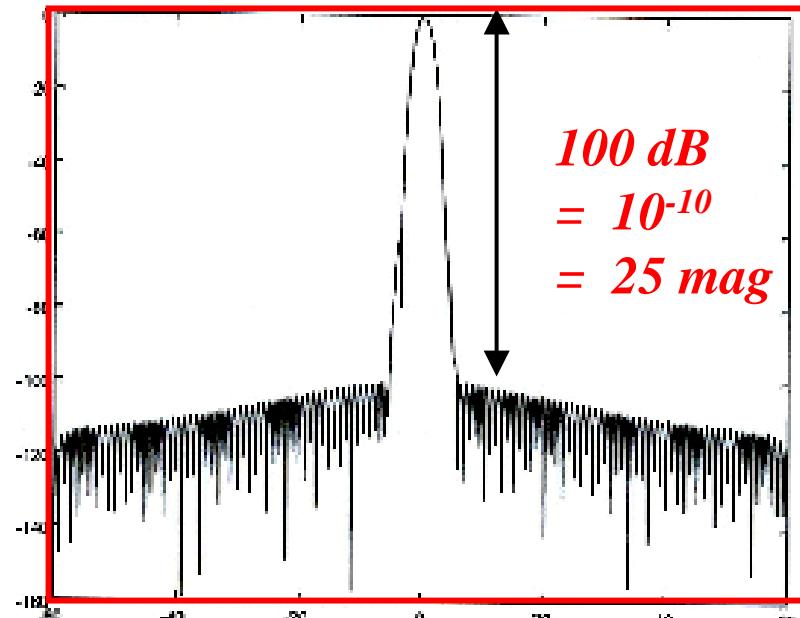
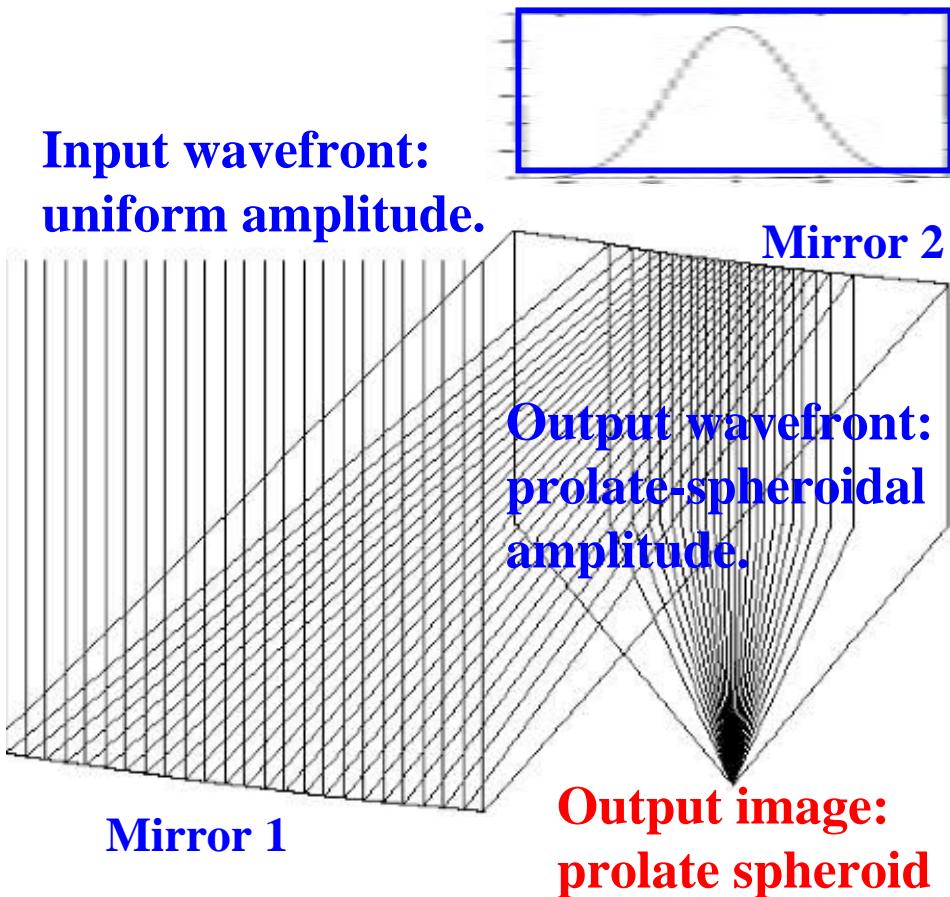
Shaped-pupil mask



$$A(x, 0) = \exp(-(\pi x/\lambda)^2)$$

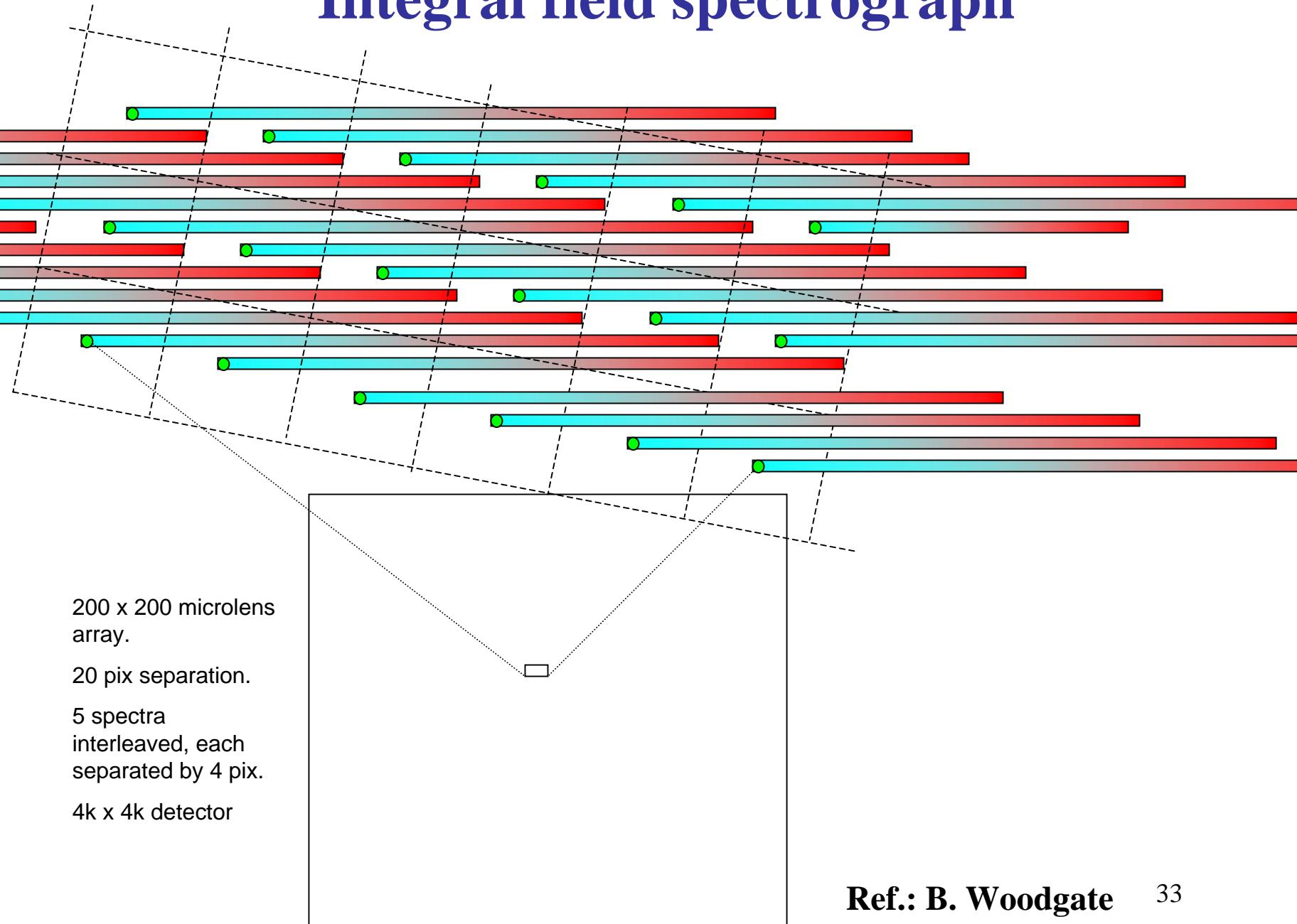
$A(0, y)$ = periodic & messy

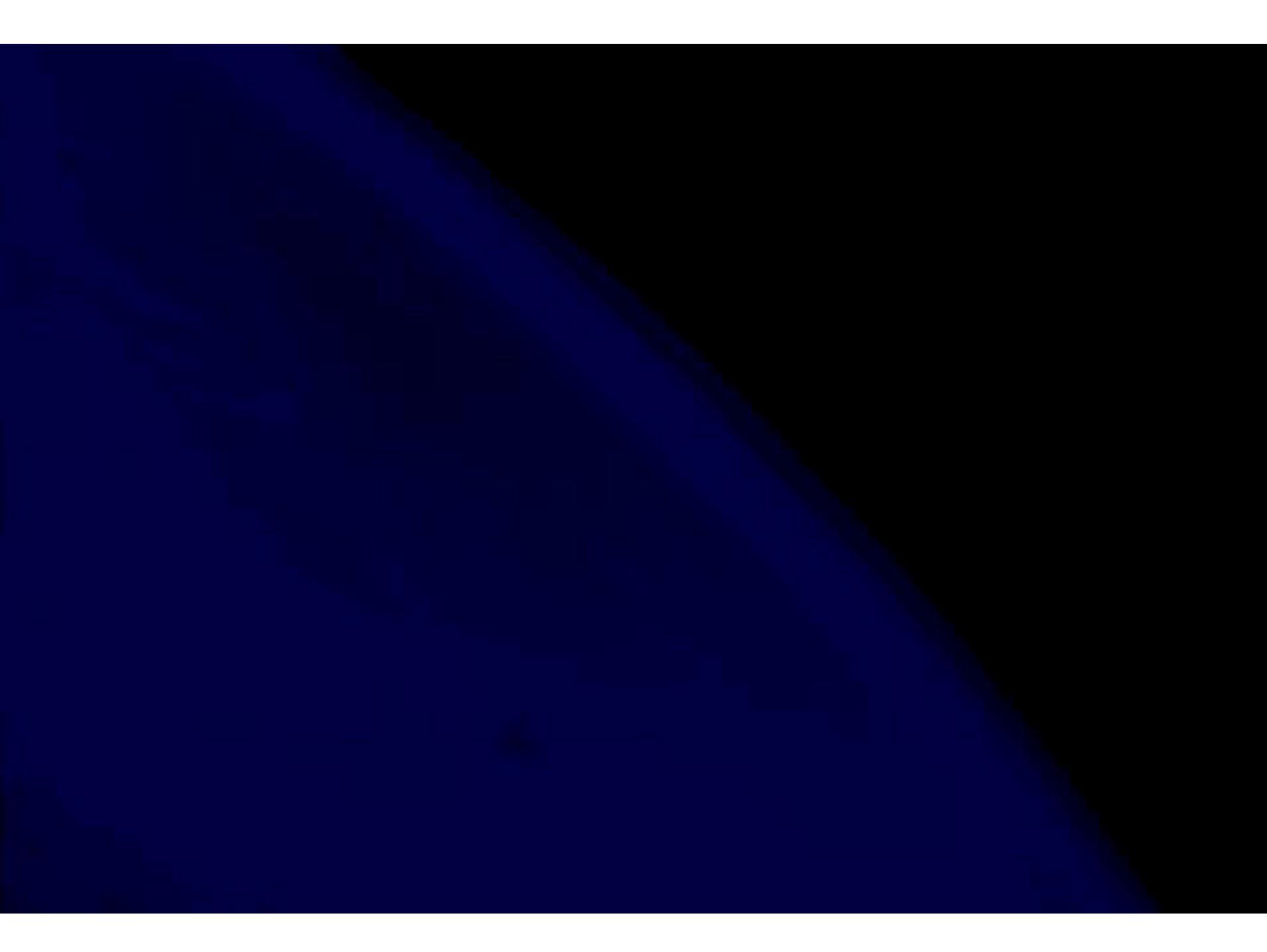
Continuous-mapped pupil



Compact star image, easily blocked

Integral field spectrograph





Coronagraph: 6 x 3.5 m

